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SOVIET ROBOTS ON THE MOON

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SOVIET ROBOTS ON THE MOON

D. Podolskiy

ABSTRACT. Since 1966 lunar exploration has made great progress, the result of the manned American flights and the unmanned Russian "automatic cosmonauts," Luna 16 and Lunokhod 1. Results are comparable, but unmanned flights are less expensive, less risky and provide the best method for future exploration of other planets. Luna 16 explored the Sea of Fertility in 1970, for age, type of soil, color, density, etc. Soil samples were returned to earth for study for the first time, and confirmed that the plains were flooded by lava. Lunokhod 1, landed by Luna 17 in November 1970, confirmed the theory of the formation of the lunar crust by its experiments near the edge of the western section of Mare Imbrium. Lunokhod 1, a self-propelled laboratory on wheels, explored over 10 km over a period of 10 months prior to ceasing operation. Experiments ranged from determining bearing capacity of the surface, mechanical properties, and soil analysis, to the study of the decrease in the intensity of cosmic radiation, proton eruptions, X-ray radiation, the exploration of distant regions of space by X-ray telescope, and joint experiments with the French with a laser reflector.

A new era in lunar research began in 1966 when Luna 9 made a soft landing /171* on Oceanus Procellarum. Minute details of the lunar landscape could be recognized from a short distance away for the first time. The American manned moon flights in Apollo spacecraft mark a new stage in the development of the exploration of the moon. Examination of soil samples from different areas of the moon is of primary interest to scientists because the results will make it possible to draw conclusions as to the origin of the moon and of prehistoric times on earth. The "automatic cosmonauts" Luna 16 and Lunokhod 1 have the advantage of permitting experiments to be made at lower costs than is possible with manned flights to the moon, and the risks involved are considerably less than those of manned flights. The results achieved with the automated equipment are the equal of the results of manned expeditions. Automated robots are, at least in the new future, without competition from man in the exploration of the planets of the solar system.

* Numbers in the margin indicate pagination of the foreign text.

Luna 16

Luna 16, the Soviet station, was launched on 12 September 1970. It made a soft landing on the moon, on the Sea of Fertility (Mare Fecunditatis), on the east side of the moon facing the earth (Figure 1). The landing site was about 100 km west of Webb Crater and 800 km east of the Apollo 11 landing site. The exact coordinates were 0°41'S, 56°18'E. Luna 16 did some drilling at the landing site, and collected soil samples which were transported back to earth by a return vehicle which was launched by firing its rocket on the moon. This was the first time the complicated task of collecting solid rock samples on a planet in our solar system by an automatic process, and of returning them to the earth, had been solved.

Luna 16 was launched by an artificial earth satellite. The rocket entered its flight path with such a high degree of accuracy that only one course correction was necessary to bring Luna 16 to the mathematically calculated point for the approach to the vicinity of the moon. The soft landing was only 1 1/2 km off target. A soil extraction device had been installed on board Luna 16. It comprised a drill, rods on which the drill was mounted, and electric drive units which permitted the system to move on three axes. The system was started upon command from the ground. The electric drill was brought into contact with the lunar surface layer by a manipulator. Drilling was to a depth of 35 cm. A soil sample was extracted and stored in a container in the return vehicle. The speed with which the drill penetrated the rock could be monitored from the ground and estimates of the hardness, or load bearing capacity, of the soil could be made for the drilling site. Radiation measurements also were made.

After completing its research program, Luna 16 restarted on the moon to return to earth. This was the first time a rocket had been launched automatically from a planet in the solar system other than earth for a return flight to earth. Luna 16 returned to earth on a ballistic flight path, found the calculated reentry corridor into the atmosphere, and landed on the territory of the USSR with great precision.

Mare Fecunditatis shows traces of gradual, quiet sinking. The "shores" are without circular, mountainous walls; their contours are dissected. This mare resembles a plain covered by flat (100 to 300 m) branch-type waves. There are no radiating systems of large craters in this region. The samples show this to be a young region of the lunar surface. The drill entered the loose lunar top layer, the regolith, relatively easily. The total weight of the Luna 16 core was slightly more than 100 g. The lunar soil in this area was found to be a dark gray to blackish powder with widely varying grain sizes, with small grain fractions averaging some 0.08 to 0.1 mm predominating over other sizes (Figure 2). The samples remind one of wet sand, or the crumbly structure of our soils. Despite good adhesive properties, the sample can be sieved easily. Remarkable is the fact that the soil has a high electrical conductivity.

Grain sizes in the soil increase with increasing depth (Figure 3). The grains of molten rock found in the soil have a high luster and sparkle against the dark background of powdered soil. Greenish and grayish brown minerals with rupture traces can be differentiated clearly among the crystalline bodies under microscopic examination. The rock particles are varieties of basalt, for the most part (see table).

The physical properties of the lunar material differ from those of earth rocks. For example, density of the material varies between 1 and 2 g/cm^3, approximately; heat conductivity in a vacuum is very low. The mean value of the /172 specific h[illegible] of the soil corresponds to that of terrestrial rock.

The findings, which basically correspond quite well with the American studies, confirm the hypothesis that the lunar maria are plains which were flooded by volcanic lava at some point in time. Rock of the basaltic type forms as that part of the internal material of a planet that melts most easily. It may be surmised that the differentiation of material on the earth, moon, and probably other planets of the earth type as well, has followed a similar course, but has progressed to different stages of development. Thus, the study of lunar material provides an insight into those processes which occurred on the earth during its early stages (compare the paper of H. Wänke in this publication).

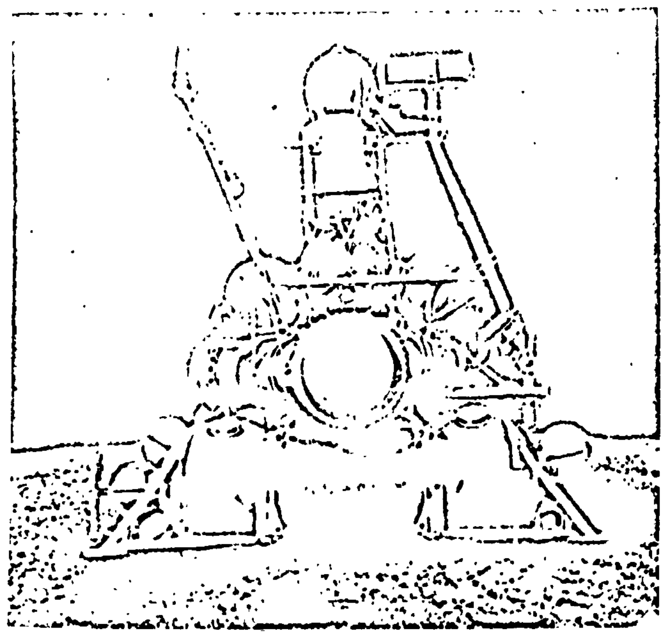

Figure 1. The automatic station, Luna 16, which made a soft landing on the moon during the "night" of 20 September 1970 (Photo: APN)

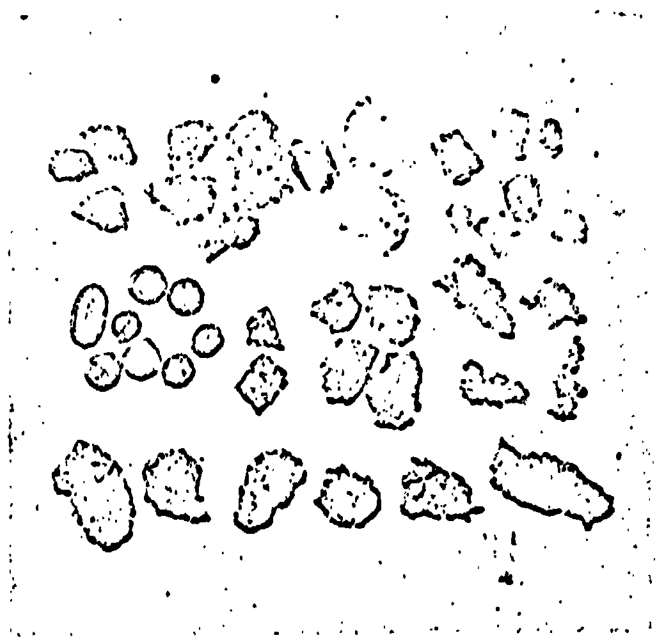

Figure 2. The major types of particles of shattered moon rock (regolith); magnified. (Photo: APN)

CHEMICAL COMPOSITION OF THE LUNAR SURFACE/IN PERCENT BY WEIGHT

Element	Mare Tranquillitatis*			Sinus Medii* Middle Bay	Oceanus Procellarum*		Crater Tycho*		Mare Fecunditatis**		Mare Imbrium***
	Surveyor 5	Apollo 11		Surveyor 6	Apollo 12		Surveyor 7		Luna 16		Lunokhod 1
	Fine fraction	Fine fraction	Rock	Fine fraction	Fine fraction	Rock	Fine fraction	Rock	Fine fraction	Rock	Fine fraction
Si	21	20	20	23	20	19	21	21	20	20	20
Fe	9	12	14	10	13	17	4	3	13	15	12
Ca	10	8	7	9	7	8	13	13	9	7	8
Al	8	6	6	8	7	6	11	14	8	7	7
Mg	3	5	5	4	7	7	4	2	5	4	7
Ti	4	5	6	2	2	2	<0.4	<0.7	2	3	<4
K	-	0.1	0.2	-	0.3	0.05	-	-	0.08	0.12	<1
Na	0.5	0.4	0.4	0.6	0.3	0.3	0.5	0.3	0.3	0.2	-

* L. D. Jaffe, Paper, XIII COSPAR, Vol. 1, Leningrad, 1970

** A. P. Venogradov, Pravda, 29 October 1970

*** Preliminary results

Lunokhod 1

The moon probably was heated by heat released from the decomposition of natural radioactive elements during its early stages, in the same way as was the earth. A differentiation took place in lunar material during this time. The rock which melted most easily flowed to the surface and formed the lunar crust upon cooling. Many scientists are of the opinion that a less dense crust formed first. This crust then was penetrated by large meteorites, or volcanic eruptions, at a later point in time. This resulted in magma eruptions, a denser rock was formed, and now comprises the surface layer of the lunar maria and oceans. The original lunar crust, which consisted of lighter rock, therefore would have to be found on the lunar continents. This hypothesis could be confirmed by Lunokhod 1 (Figure 4), which conducted its scientific experiments in the western section, near the edge of the Sea of Rain (Mare Imbrium). The Lunokhod 1 operating area was some 40 km south of Promontory Hereklides, which forms the southern boundary of the Gulf of the Rainbow (Sinus Iridum)

(38°17'N, 35°00'W). Here an area with the characteristics of a mare changes into a mountain region.

The self-propelled "automated moon explorer" was landed on the moon by Luna 17, which was launched on 10 November 1970. Lunokhod 1 was a complex space laboratory, equipped with control units, a radio transmitter, scientific experiments, and a television camera. Lunokhod 1, and all its instruments, were controlled by a team in the Cosmic Telecommunication Center. Lunokhod 1 /173 moved around on the moon on the eight wheels fitted to its chassis. Each wheel had an independent drive, so that the vehicle remained maneuverable even with several wheels not functioning.

The landing area corresponded to the thoroughly explored maria of the lunar equatorial zone in its geomorphological characteristics. First of all, the bearing capacity of the upper layer of soil was determined as being 1 to 1.2 kgf/cm^2. This figure is somewhat higher than that established during the American Apollo expeditions. It can be concluded, from the way in which the lunar soil reacted when Lunokhod 1 passed over it (Figure 5), that the soil at the landing site was almost similar to the soil on earth on which the vehicle was developed. The bearing capacity of the lunar soil corresponds, approximately, to that of dust-like volcanic sand on the earth. The dynamic resistance of most of the lunar substrate corresponds on earth to that of a good dirt road; inferior sections can be compared to a good sand road.

Further studies showed that the mechanical properties of the lunar surface layer may vary greatly, and depend on the depth of the upper layer of fine grains, and on the degree of compaction. The experiments conducted by Lunokhod 1 enabled man, for the first time, to develop some idea of the possible variety of the mechanical properties of the lunar surface. The loose layer was at least 6 to 8 cm thick at the measurement points. Here, the top 1 to 2 cm thick layer had a looser structure, and a lower bearing capacity. The bearing capacity of the surface varied between 0.2 and 1.0 kgf/cm^2.

Figure 6 illustrates the distribution of bearing capacity values for a partial section of the area explored. It shows that the soil is very inhomogeneous. A value of 0.34 kgf/cm^2 for the bearing capacity is most common.

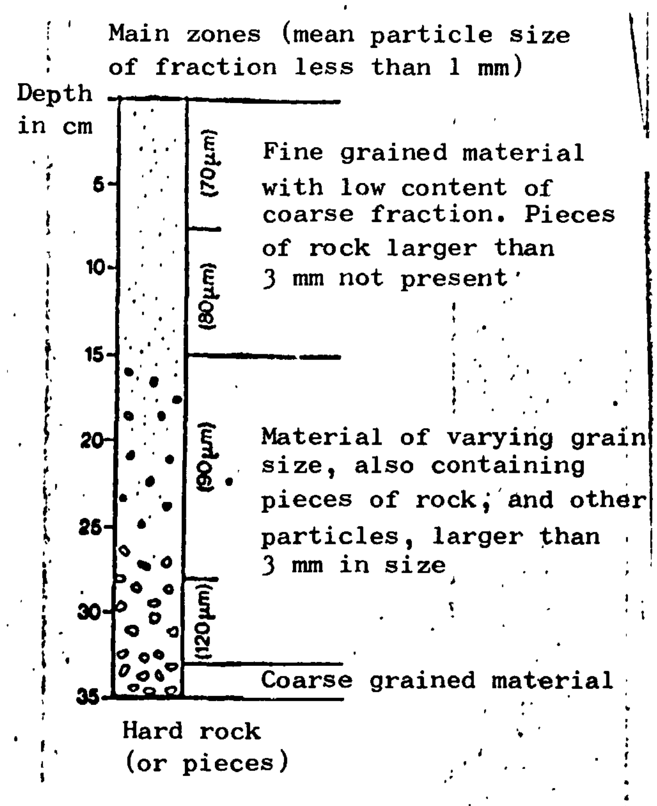

Figure 3. Schematic representation of a column of lunar soil illustrating the distribution of grain sizes in the soil.

The data collected, and this agrees with the soil samples from Luna 16 which have been studied, showed that the lunar surface was loose along the path traveled by Lunokhod 1, and that its mass per unit volume was 1.5 to 1.7 g/cm^2 in its natural stratification.

Lunokhod 1, by appropriate driving maneuvers, was able to examine a crater 30 cm in diameter, one of the very young craters, according to the classification by selenologists. A meteorite apparently had penetrated at this point relatively recently. Rocks which have been ejected from a depth of several meters, were strewn around the crater. Lower-lying layers of the lunar surface could thus be examined without drilling. Experts have determined that this comparatively young crater was formed some 2 to 3 million years ago, and that the rocks which form Mare Imbrium are close to 3 billion years old.

Profiles were made through all the craters through which Lunokhod 1 traveled on its excrusions, which covered more than 10 km. Evaluation of the

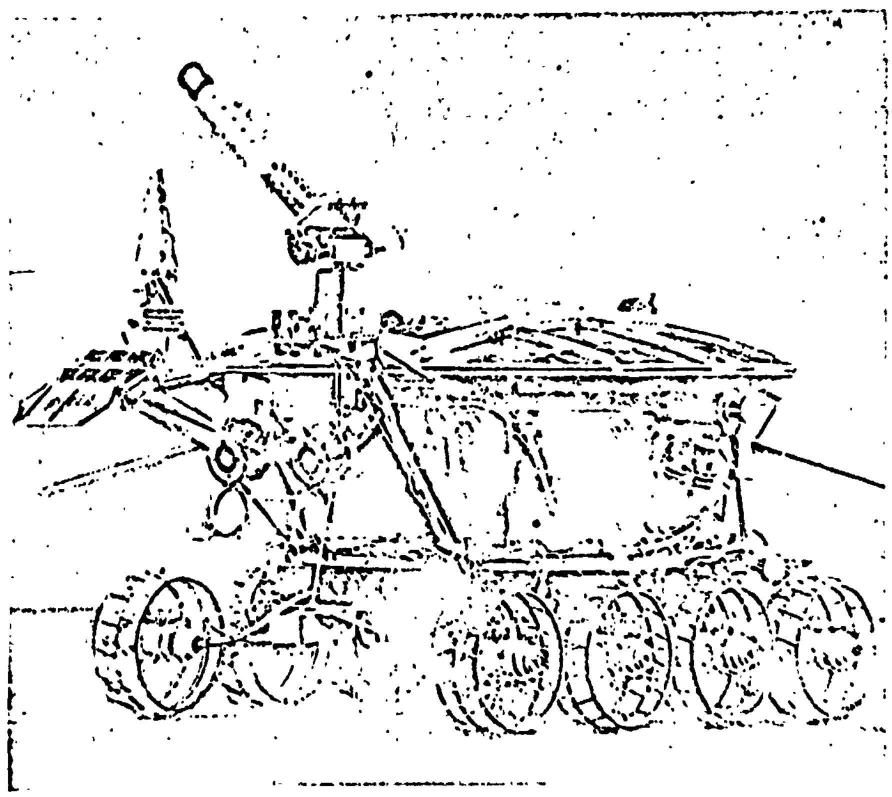

Figure 4. Lunokhod 1, the self-propelled automatic unit, was landed on the moon by Luna 17 which made a soft landing on Mare Imbrium on 17 November 1970. Lunokhod 1 covered 10,540 m in 10 1/2 months and ceased operation in mid-October 1971. (Photo: APN)

television panoramas revealed that the lunar surface is very inhomogeneous, so far as topography is concerned. Large formations show against the general background, sometimes in the form of a great many craters. The predominant shapes among them are flattened formations without clearly distinguishable sloping edges. Young craters with a clearly defined edge and wall are rare. Craters with diameters of up to several kilometers cover the surface of Mare Imbrium more or less uniformly. The density of the distribution, and the relationship between the number of craters per unit area and the diameter, are almost the same as those for the maria of the equatorial zone of the near side of the moon. Individual areas with dimensions of several tens of kilometers fall outside this pattern; here the density of the distribution of the small craters is greater than the mean by one order of magnitude. These obviously are accumulations of secondary craters formed in connection with the eruptions of large craters. It has been established that the plains of the lunar maria are extensive basalt eruptions. The original rock is covered with a layer of finely divided rock and stones, regolith, whose thickness is less than 10 m, and 5 m in the area investigated. /174

Two factors have influenced the development of the lunar surface in the area explored:

1. the formation of impact-explosion and impact craters with sharp lines, associated with rock eruptions;
2. the decomposition of the craters as a result of surface erosion and destruction by rocks.

A part of the Lunokhod 1 scientific program was a study of cosmic radiation. Even though no major solar activity was expected during the experiment, proton fluxes in the energy range from 1 to 5 MeV were recorded right at the beginning of the flight of Luna 17, far exceeding the mean background fluxes of these particles in interplanetary space (by a factor of 10^2). The intensity gradually decreased, to 1/5th, during the four days of the flight to the moon. Recorded during this same period was a gradual reestablishment of intensity of galactic cosmic radiation with energy above 30 MeV. In general, the entry of galactic cosmic radiation into the solar system is made more difficult by an increase in the intensity of the solar protons.

The probe Venera 7, which was en route to Venus at that time, carried the same instrumentation as Luna 17 and Lunokhod 1. The probe was 30 million km from the earth at that particular point in time. A comparison of the data and findings showed that the effects recorded on the flight to the moon also were observed in the Venera 7 area.

Subsequent analysis, in which data on the sun, and Venera 7 recordings also were utilized, showed that the last phase of the intensity decrease had been recorded after a strong increase in solar protons. This increase had been caused by an enormous proton eruption on the sun (intensity 3 B), which occurred on 5 November 1970, at 0323 GMT.

Figure 5. Panorama of the moon and the first track of the automatic Soviet excursion vehicle Lunokhod 1. This picture of the lunar surface was taken on 17 November 1970, in the evening, during telecommunication with the lunar vehicle. The impressions of the wheels are similar to the tracks of a tractor on loose soil. (Photo: TASS-APN)

Extremely interesting data were recorded on the second day on the moon, when a strong increase in the intensity of solar cosmic radiation was recorded. It started on 12 December, and reached a maximum on 13 December, when the background level was exceeded by a factor of 10^4. The cause of this phenomenon was a series of solar eruptions on 10 and 11 December 1970. The sudden beginning of a magnetic storm was recorded on earth on 14 December at 0154 GMT, and at the Deep River (Canada) meteorological station a Forbush decrease by 4.5% was recorded for the intensity of galactic cosmic radiation. The sudden decrease in the intensity of protons with energy levels of 1 to 5 MeV, recorded by Lunokhod 1 on 14 December, corresponds to the intensity minimum of galactic cosmic radiation during the Forbush decrease. Thus, this phenomenon can be explained by the arrival on the moon and on the earth of plasma which had been ejected from the sun during a solar eruption. The simultaneous recording of this phenomenon by Venera 7, which was 60 million km from the moon at that time, was of special value. On the basis of earlier data, and those recorded by Venera 7 and Lunokhod 1, it can be concluded that the sun's proton activity has been decreasing gradually since its maximum in 1968 to 1969. A more pronounced decrease has been observed since mid-December 1970.

Lunokhod 1 also was used for the first attempt to use the planet closest to us to explore the more distant regions of space. An X-ray telescope, which had been installed on board, measured the background of outer-galactic X-ray radiation at periodic intervals. Studies of this kind are highly valuable to cosmology because many processes taking place in the remote reaches of space can be observed in this spectral range. This spectrum of X-ray radiation cannot be observed on earth because the atmosphere absorbs it completely. The brevity of space observations by earth satellites and rockets has given X-ray astronomy factual data gathered in a total time of 3 to 4 hours.

It is important that the moon has no radiation zone to form a serious barrier to observations of X-ray radiation from orbits in the vicinity of the earth. The background of charged particles is determined primarily by cosmic radiation on the moon, the flux of which is comparatively low. In addition, observations from the lunar surface provide a way to gather a weak signal from an X-ray source over an extended period of time, something that cannot be done /175

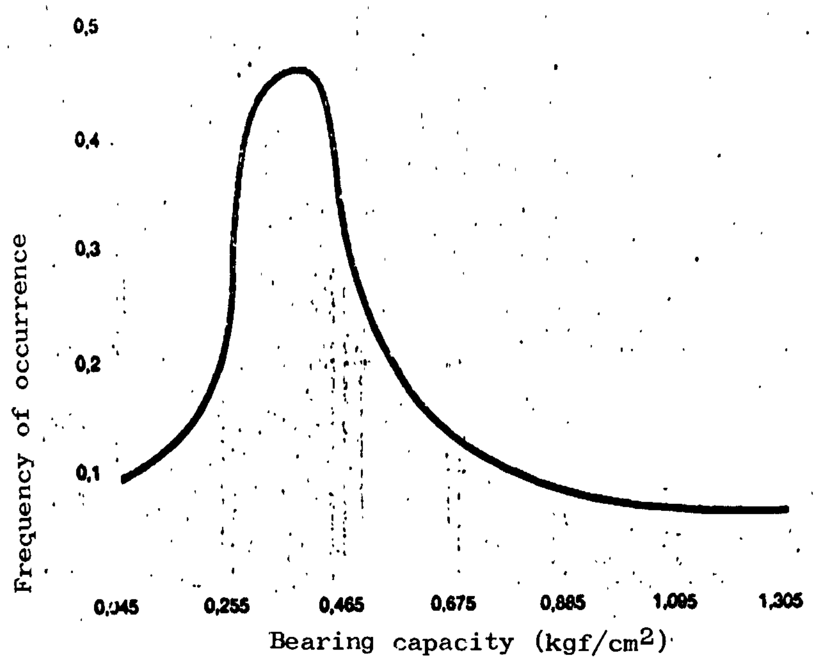

Figure 6. Distribution of bearing capacity values for the lunar surface, as determined by Lunokhod 1.

during studies using satellites and interplanetary stations. It is possible to observe extremely weak sources, even with small telescopes, in this way.

The main components of the X-ray telescope on Lunokhod 1 were two proportional X-ray quanta counters in the energy range from 2 to 10 keV (wavelenghts 1 to 6 Å). Collimators were arranged in front of the counters to limit the field of vision of each counter to a cone with an aperture of 3.5°. The axes of the counters were aimed at the local zenith when Lunokhod 1 was in a horizontal position. The inlet window of one counter was covered by a filter impenetrable to the range of X-ray radiation studies, so that one counter recorded cosmic X-rays, and the background of cosmic particles, while the other recorded only the particle background, and thus served to check the results.

There are two hypotheses for explaining the X-ray background in space:

1. the background is formed by a great many such radiation sources;

2. the X-ray radiation is produced by an intergalactic gas which emits homogeneous radiation. The changes in intensity by factors of 2 to 3 from point to point, discovered by Lunokhod 1, mean that discrete sources were observed. These first measurements showed how great were the possibilities offered by Lunokhod 1 as a mobile lunar observatory. By way of contrast, rocket measurements supply data which make differentiation almost impossible between discrete sources and the background. Preliminary evaluation of the measurements made by Lunokhod 1 to date shows that cosmic X-ray radiation consists of radiation from individual sources, and from the diffuse background of space. The majority of the sources are in our galaxy, that is, they are concentrated in a relatively narrow belt (the Milky Way). A few, usually very weak sources, however are beyond the galaxy. The diffuse background is isotropic, that is, the incidence of rays is the same from all directions. It had been assumed that the background was of outer-galactic origin, and this hypothesis was confirmed by Lunokhod measurements of the diffuse background. Our galaxy plays a very small part in the development of the diffuse background. A preliminary evaluation of the results of the measurements made point to the fact that discrete X-rays, which are beyond the plane of the Milky Way, have been observed. Two sources are relatively strong, apparently.

X-ray astronomy was able to demonstrate independent possibilities to such an extent that it is hoped today that X-ray astronomy will provide the answers to many difficult questions of astrophysics, and provide insight into the development of outer space.

Lunokhod 1 also was equipped with a laser reflector developed by French scientists. The experiment to locate the moon by laser was conducted under the Franco-Soviet Agreement on Cooperation in Science and the Peaceful Uses of Space. Laser investigation makes it possible, in particular, to calculate the distance between the earth and the moon with great accuracy, far exceeding that of other methods (compare Umschau 1970, No. 12, p. 383). The experiment was conducted jointly by the French Pic du Midi Observatory and the Crimean Astrophysical Observatory (USSR).

The Other Plancts

The Soviet space research program includes many flights by automatic space stations. The flights of Luna 16 and 17 have shown that these "automated cosmonauts" are capable of performing very complex tasks and of supplying results which are in no way inferior to manned space explorations. In addition, these flights are considerably less expensive than manned space flights. The automatic equipment, at least for the near future, has no competition, particularly in the exploration of the planets in the solar system. Planets such as Venus, Jupiter, and Saturn will remain impenetrable to man for a long time to come because of the complexity of their natural conditions.

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